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Design of Landing Gear for Medium Altitude Long Endurance (Male) Unmanned Aerial Vehicle

Alex Avwunuketa* Gabriel Udu Anthony Adeleke Lawal Adamu
Oluwatofunmi Ajao Eze Okoro
Department of Aircraft Engineering, Air force Institute of Technology, Kaduna, Nigeria

Abstract

This paper examines the procedure adopted for the design of UAV landing gear. Aircraft landing gear serves as a mechanism to support weight of the aircraft during landing, take-off , taxiing and also provide a shock absorbing function. The design of landing gear for the Medium Altitude Long endurance unmanned Aerial Vehicle is simple and it is base on safe life and fail safe concept and at the same time, make optimum selection and used of high strength materials for the design.This design considerations for this landing gear are significantly different, but past design procedures were used as guide to this design .Various landing gear configurations and types are in used today. The most common landing gear use for UAV is the fixed tricycle arrangement with one nose wheel (NLG) and two main wheels (MLG) at the rear. The retractable tricycle type was adopted for this design. The most attractive feature for this design is the improve stability during braking and ground maneuvering. The result obtain from this study indicate that the landing gear stability of the UAV could be improve with longer wheel axle, by increasing the wheel track.The approach used for the design, of the landing gear for this Medium Altitude Long Endurance UAV, follows the recommendations from previous designs of UAV landing gear and federal Aviation Regulation (FAR).

Keywords: CG, Landing Gear, shock absorber ,UAV, Wheel Base, Wheel track.
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1.0 INTRODUCTION

The section contains definition, classification and functions of unmanned aerial vehicle and Landing gear systems.

1.1 Unmanned Aerial Vehicle

An unmanned aerial vehicle (also known as a drone) is a flying machine or a remotely piloted aircraft, without a human pilot on-board or passengers. Therefore, "unmanned" means total absence of a human who directs and actively pilots the aircraft (Dalamagkidi, et al 2009).

UAVs come in two class: some are controlled from a remote location and others fly autonomously based on pre-programmed flight. There is a wide variety of UAV shapes, sizes, configurations, and characteristics (Akhilesh, 2009)

UAVs has various functions, such as remote sensing that is centered to the reconnaissance role must UAVs fulfill, other functions include research and development, to search for and rescue people in unsafe locations, transportation and for combat. Anka, Bereta, Nishant, watch- keeper, Predator, Tsegumi, Amebo, Global Hawk are in the list of UAVs.

The landing gear system required for the UAV has the conventional take-off and landing.

1.2 Landing Gear

The landing Gear is a mechanical system that absorbs landing and taxi loads as well as transmits part of these loads to the airframe so that majority of impact energy is dissipated. The landing gear is a major component of the aircraft. It support the aircraft on the ground and allows it to taxi, take-off and land. The landing gear serves the following purpose;

- It keep the aircraft stable on the ground and during loading, unloading, and taxi;
- It allow the aircraft to move freely and maneuver during taxiing;
- It provide a safe distance between other aircraft components such as the wing and fuselage while the aircraft is on the ground to prevent any damage by the ground contact;
- It absorb the landing shocks during landing operations;
- It facilitate take-off by allowing aircraft acceleration and rotation with the lowest friction.

1.3 Landing Gear Arrangement

Landing Gear are generally categorized by the number of wheels and their pattern (Currey,1988). The landing gear could be fixed or retractable.

- Single main Gear

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- Bicycle Gear
- Tail Gear
- Tricycle
- Quadricycle
- Multi- Bogey
- Releasable rail
- Skid

From the above mentioned types of landing gear configuration, the retractable tricycle types with nose and main gear attached to the fuselage has an advantages over other layout. Generally, the analytical solution of UAVs landing gear layout has received very little attention. One reason for this neglect is that it has a very wider classification and applications (Akhilesh ,2009).

The traditional landing gear design process for transport aircraft has described in textbooks (Currey & Raymer,) Therefore, in this paper main and nose wheel landing gear layout design for unmanned aerial vehicle has been described on basis of theoretical kinematics and international standard (FAR).

2.0 Landing Gear Layout Design Parameters

This section represents the steps and approach that were adopted by the landing gear designer during conceptual design phase.

2.1 Landing Gear Location

This Unmanned Aerial Vehicle has two CG position, 15%MAC for fwd CG corresponding to full fuel mass at take-off and 30%MAC for aft CG corresponding to when fuel has been used at the time of landing.

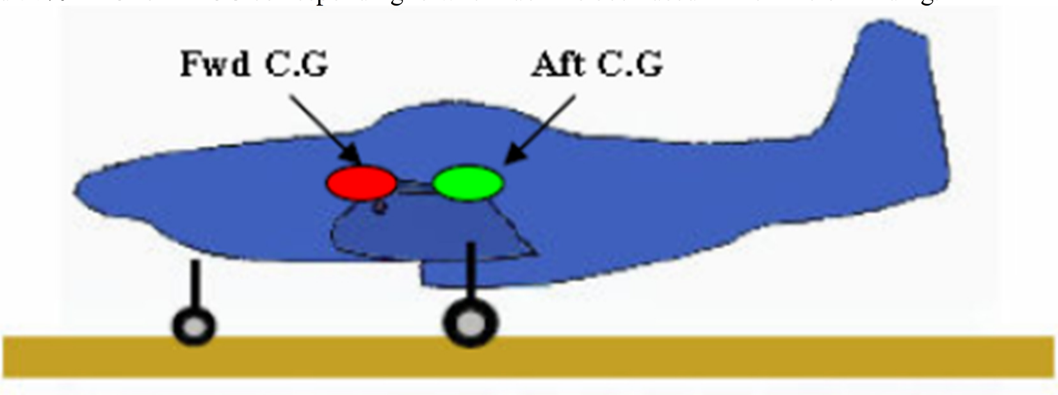

Figure 1. UAV with two C.G. Position

The location of the main landing gear should be between 50% - 55% of MAC (Currey, 1988). For this design 55% of MAC was adopted.

The nose landing gear should be located as far forward as possible to minimize its load, maximize floatation and maximize stability (Currey,1988). The appropriate layout of the landing gear ensures satisfactory loads distribution affecting pitch stability, ground maneuverability (steering) and tail clearance in the longitudinal sense (Kuryleski,2012).

The position of the main and nose landing gear were calculated using below equations

2.2 Positioning of the Main Landing Gear

XMLG= WRD +W+0.55MAC (Young, (1)

XMLG=2.4+0.181+0.55×0.90
XMLG=3.076m

2.3 Calculating for Wheel Base

Was calculated using below equation

$$W_B = \frac{0.36\times MTOW}{0.15\times MTOW} \tag{2}$$

W_B=2.4m
Wheel base 2.4m

2.4 Calculating the Wheel Track

$$W_T = 2\times W_B\times \mathrm{Tan}\left[\frac{\sin^{-1}\left(\frac{H_{CG}}{Tan\,55°}\right)}{l_n}\right] \tag{3}$$

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$l_{n=}$ 2.04m

W_T = 2×2.4 ×Tan[$\frac{sin^{-1}(\frac{1.04}{1.428})}{2.04}$]

W_T= 4.8 ×Tan 23.2°

W_T = 2.1m

Wheel track =2.1m

2.5 Positioning of the Nose Landing Gear

$$xNLG=xMLG - W_B \tag{4}$$

W_B=wheelbase

W_B=2.4m

xNLG= 3.076 - 2.4

xNLG= 0.676m

2.6 Static Load of the Landing Gear

The main and nose gear static loads where calculated using the formula below;

$$R_M = 0.425 \times MTOW \tag{5}$$

$$R_N = 0.15 \times MTOW \tag{6}$$

R_M= Static load on MLG

$R_{N=}$ Static load on NLG

MTOW=Maximum take-off weight

MTOM= 650kg

g= acceleration due to gravity= 9.81m/s²

R_M = 0.425 ×9.81 ×650

R_M = 2,7100N

R_N = 0.15 × 9.81 × 650

R_N = 956.475N

The static load distribution between the nose and main landing gear positions is calculated according to the values and dimensions for the specification. The aircraft weight is supported by the nose and the main landing gear. The reaction factor of 1.33 was assumed for UAV (STANAG 4671), which determines the maximum normal landing reaction on each unit is a constant for main and nose landing gears (Dalamagkidi et al 2009). The location of the main landing gear (MLG) from the aircraft nose is 3.076m that correspond to 55%MAC.

Table 1 Static load distribution

POSITION/ REACTION	FORE CG	AFT CG
CG POSITION – X	2.724m	2.851m
LN – (NLG – X position	0.36m	204m
LM – (MLG – X position)	0.324m	2.076m
RM – MLG Static Reaction (per strut)	5420.025N	5515.67N
MLG % Load Distribution	85%	86.5%
RN – NLG Static Reaction	956.475N	860.83N
NLG % Load Distribution	15%	13.5%

3.0 Tire Selection

The tire carries the load almost entirely by its internal pressure. Tire sizing includes the calculation of the tire outer diameter (D_t) and the tire width (W_t),then selecting the closest tire in the market from a manufacturer's catalog Mohammad, 2013).

Tire selection should be based on the smallest diameter rated to carry the desired dynamic and static loads (Raymer, 1992). The tires are sized to carry the weight of the aircraft. Typically the main tires carry about 90%% of the total aircraft weight. Nose tires carry only about 10% of the static load, but experience higher dynamic loads during landing (Raymer, 1992). For this UAV design, the main tire carry 85% of the aircraft weight, while the nose landing gear carry 15% of the aircraft weight. With the main landing gear layout and static loading established, tire selection is possibly considered and recommended by the Goodyear aircraft tire catalogue (Global Aviation Tire)

A newly designed aircraft, should be provided with an allowance that will compensate for an increase in loading capability. Growth are generally experience during the complete aircraft life cycle, start from the prototype to the first production units and moving to heavier weight versions to meet the requirements of the aircraft operators. The selection of a tire that permits an increased load rating capability will avoid the costly necessity of a change in tire size or wheel details required to support the heavier version aircraft. The main wheel tire

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requirements should be based upon the most aft centre of gravity location and the ground operational load-speed-time. History considered being the most severe during normal service operations (Oluwole,2013)

Also, as specified in the CS 23 that a requirement of wheel tire whose approved tire ratings (static and dynamic) is not exceeded by a load on each main wheel tire (Oluwole,2013) The MTOW condition at the aft CG remains the critical design case for tire loading (.Oluwole,.2013).

3.1 Tire Selection Criteria

The criteria used for selecting Landing gear tire were based on suggested condition by [3] in conformity with CS 23. These conditions include, the static load rating must be compatible with the applied loads and the 25% growth in aircraft weight should not require a change in tire or wheel size (Oluwole,2013).

3.2 Tire Sizing

For each main wheel, W_m= 1.25×609.13

W_m=761.4lb

$$D_{tire} = \mathrm{a}\times(W_m)^{\mathrm{B}} \tag{7}$$

For the calculation of Tire (wheel) diameter, use equation (7)

For general aviation and UAVs

a= 1.51 B= 0.349

D_{tire}= Tire(wheel) diameter

a=1.51, B=0.349 , W_m= 761.4lb

D_{tire}= 1.51×(761.4)$^{0.349}$

D_{tire}= 15.3inch

D_{tire}=15.3×0.0254

D_{tire}=0.390m

D_{tire}=390mm

The outside diameter For the MLG=390mm

$$W_{tire} = \mathrm{a}(W_m)^{\mathrm{B}} \tag{8}$$

Equation (8) is for the calculation of tire(wheel) width

W_{Mtire}= Tire width, a=0.715, B=0.312 W_m= 761.4lb

W_{Mtire}= 0.715(761.4)$^{0.312}$

W_{Mtire}= 5.7inch

W_{Mtire}=5.7×0.0254=0.145m

W_{Mtire}=145mm

The tire width for the MLG = 145mm

Since the UAV is for combat, there is a tendency that it might be operated from rough unpaved runway

The calculated values of wheel diameter and width should be increase by 30% if the aircraft is to operate from rough unpaved runway (.Raymer, 1992)

D_{Mtire}=1.3×15.30=20.0inch

W_{Mtire}=1.3×5.70=7.40inch

For the nose landing gear

The nose wheel diameter and width is assumed to be 60-100%of the diameter and width of the main wheel (Raymer,1992). For this design 60% is applicable

D_{Ntire}= 0.6×20.0=12.0inch

W_{Ntire}=0.6×7.4=4.44inch

From the Goodyear aircraft tire data

For MLG

Size=20.4×7.40

Rated speed=174kt

Rated inflation=125psi

For NLG

size=12.0×4.44

Rated speed=160mph

Rated inflation=75psi

4.0 Shock Absorber

Shocks during landing and taxiing needs to be absorbed by the landing gear. And loads need to be reduce to an acceptable level. Both the tire and the shock absorber take up most of the loads. Shock absorbers can be constructed

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differently. They can be made of solid steel springs, rubber springs or a fluid spring with gas and/or oil (Oleo-pneumatic). An oleo-pneumatic fluid spring is the type of shock absorber that is consider for the UAV, because of its relative low weight and high gear efficiency. The oleo concept was patented in 1915 as a recoil device for large cannons. which forces oil through a small hole (orifice). For maximum efficiency, many oleos have a mechanism for varying the size of the orifice as the oleo compresses ("metered orifice") (.Raymer, 1992).

The oleo combines a spring effect using compressed air with a damping effect using a piston.

The total aircraft energy that must be absorbed at touchdown, must be equal to the kinetic energy of aircraft, derived from the vertical velocity at touchdown. For the design of Oleo-pneumatic shock absorber, the following parameters are to be consider:

- Stroke.
- Length of Oleo.
- Inner and outer diameter.
- Internal spring sizing.

The stroke depends on the vertical velocity at touchdown, the shock absorbing material and the amount of wing lift that is available after touchdown. As a rule- of thumb, the stroke in metre is equal to the vertical velocity at touchdown in (m/s).The vertical speed of the UAV at touchdown is 1.55m/s, therefore its stroke is 1.55m.

4.1 Shock Calculation

During landing, the shock absorber and the tire must absorbed the kinetic energy of the aircraft.

$$\text{Tire energy} = \partial t \times \eta_t \times \lambda M \tag{9}$$

∂t=Tire deflection(m)
η_t=tire efficiency(0.47)
λ=Reaction factor(1.33)
M=aircraft Mass(650kg)

$$\text{Struct energy} = S \times \eta_s \times \lambda M \tag{10}$$

S=vertical axle travel (0.115m)
η_s=shock absorber efficiency(0.80)

$$\text{Kinetic energy of aircraft} = 0.5 \times M \times (Vv)^2 \tag{11}$$

From the law of energy conservation
Kinetic energy of aircraft=Tire energy + shock absorber energy

$$\frac{1}{2} M \times V_v^2 = \partial t \times \eta_t \, \lambda M + S \times \eta_s \times \lambda M \tag{12}$$

Divide equation by M

$$0.5 \times V_v^2 = \partial t \times \eta_t + S \times \eta_s \tag{13}$$

$1.33(\partial t \times 0.47 + 0.115 \times 0.80) = 0.5 \times (1.55)^2$
$\partial t = 1.73$m
The total length of Oleo including the stroke distance and the fixed portion of the oleo will be 2.5 times the stroke(Raymer, 1992)
L=2.5×1.55
L=3.875m
Oleo diameter is determined by the load carried by the oleo. The main wheel oleo load is the static load of the main gear. The oleo carries its load by the internal pressure of compressed air across a piston. An oleo has an internal pressure of 1800psi (Raymer, 1992)
P=1800psi= 12,600kN/m²

4.2 Oleo Internal Diameter

Oleo load= 2,710N

$$\text{Area of the oleo} = \frac{Oloe\ Load}{Internal\ Pressure} \tag{14}$$

Area of the oleo= $\frac{2710}{12,600 \times 1000}$
Area of the oleo=0.000215m²

$$\text{Area} = \frac{\pi d^2}{4} \tag{15}$$

$d^2 = \frac{4 \times 0.000215}{3.142}$
$d^2 = 0.0002737$
$d = (0.0002737)^{0.5}$
d=0.0165m=16.5mm

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4.3 Oleo External Diameter

The internal diameter of the oleo is 16.5m.The external diameter of the oleo is 30% greater than then internal diameter (.Raymer, 1992). The external diameter is calculated as

$$D = 1.3\left[\frac{4\times O_L}{\pi\times P_i}\right]^{\frac{1}{2}} \tag{16}$$

$D=1.3\left[\frac{4\times 2710}{3.142\times 12{,}600\times 1000}\right]^{0.5}$

$D = 0.0215$m

D=21.5mm

4.4 Moment of Inertia for The MLG

The struct for the landing gear has a circular cross-section. The second moment of inertia for the MLG

$$I = \frac{\pi}{64}[D^4 - d^4] \tag{17}$$

$I = \frac{3.142}{64}[0.0215^4 - 0.0165^4]$

$I = 6.85\times 10^{-9} m^4$

5.0 Results and Discussion

To ensure that the nose landing gear (NLG) does not carry too much or too little of the load, equations (18) and (19) is recommended for evaluation and validation (Raymer, 1992)

$$\frac{L_{M\,aft}}{W_B} > 0.5 \tag{18}$$

$$\frac{L_{M\,fore}}{W_B} < 0.2\ (0.08 - 0.15) \text{ is preferable} \tag{19}$$

$L_{M\,aft}$= 0.225m

$L_{M\,fore}$= 0.360m

W_B=2.4m

From figure 3 shown below , it indicate that for the CG position to shift from forward to aft of the aircraft, the load on the NLG gear should be reduce. Also for the CG position to shift from forward position to aft, the load on the main landing gear should increase. The aircraft under this design is an unmanned Aerial vehicle (UAV), it is recommended that the nose landing should be position at the most aft , to validate equation (18) .This is also applicable to the main landing gear to validate equation (19)

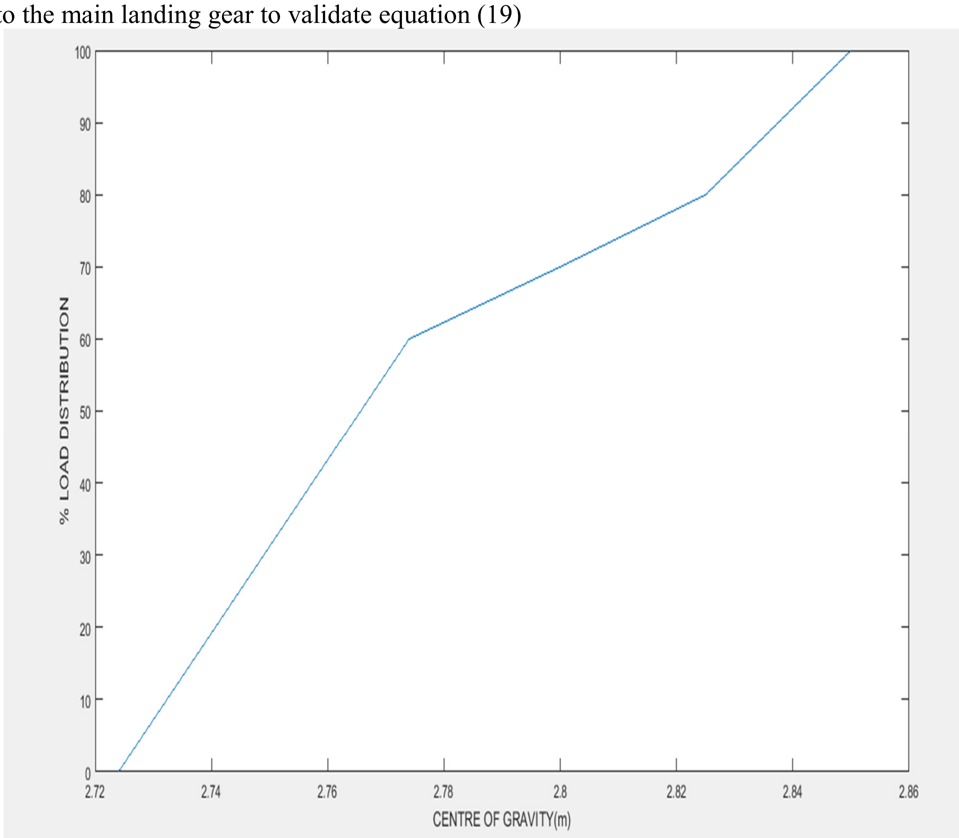

Figure 2 UAV % Load Distribution

6.0 Conclusion

Based on the present study on the design of the UAV, the following concluding remarks are drawn

- Nose landing gear loads in the static position optimum range would be 8-15%.
- Main landing gear loads in the static position optimum range is 85-100%
- The strut length is about 2.5 times the stroke length.
- The nose wheel diameter and width is assumed to be 60-100% of the diameter and width of the main wheel.
- The numerical value for vertical speed of UAV at touchdown is equivalent to the numerical value for its stroke length .
- The external diameter of the oleo is 30% greater than then its internal diameter.
- The length of the fuselage is 2.2 times the wheel base.
- The length of the wing span is 5.3 times the wheel track.

The present conceptual design can be functionally improve by using various computer simulation programs. These results needed experimental data to validate it.

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